Army Research Laboratory

UGS, UGV, and MAV in the 2007 C4ISR OTM Experiment

by Timothy G. Gregory, Jesse B. Kovach, Robert P. Winkler, and Christopher H. Winslow

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14. ABSTRACT
In the summer of 2007 as part of the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance On-the-Move (C4ISR OTM) experiment, the Army Research Laboratory (ARL) and the Communications-Electronics Research, Development, and Engineering Command (CERDEC) demonstrated the viability of integrating a variety of unattended ground sensors (UGS), unmanned ground vehicles (UGVs), and micro air vehicles (MAVs) into a Force XXI Battle Command Brigade and Below (FBCB2) based system that provides situational awareness (SA) and command and control (C2) to the lowest tactical echelons. In this report we describe the system architecture, techniques and components used to effect this integration.

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1. Introduction

Communications, Electronics, Research, Development, and Engineering Center (CERDEC's) Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance On-the-Move (C4ISR OTM) Testbed and associated experimentation began in 2001 at the direction of Dr. A. Michael Andrews, then the Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology's Deputy Assistant Secretary for Research and Technology with the creation of a Special Projects Office to support the demonstration and evaluation of C4ISR technologies for Future Combat Systems (FCSs). The 2007 experiment employed over 100 different sensor, command and control, and communications systems augmented with a simulated Brigade-sized element (*1*). In this report we describe how the Army Research Laboratory (ARL) and CERDEC integrated unmanned ground vehicles (UGVs), a variety of unattended ground sensors (UGSs), and a micro air vehicles (MAVs) into the experiment and exercise. This report focuses on the systems, subsystems, and components relevant to ARL's integration efforts.

ARL brought several UGVs, a MAV, and both operational and experimental UGSs to the experiment. UGS communications was provided by an ad-hoc network of ARL-developed "Blue Radios". Communications for the UGVs, operator control units (OCUs), and MAV ground station was provided by a mobile ad-hoc network (MANET) running on top of 802.11g. Communications from the UGSs and UGVs were routed to a High Mobility Multipurpose Wheeled Vehicle (HMMWV) serving as a communications gateway to the Soldier-Level Integrated Communications Environment (SLICE) Soldier Radio Waveform (SRW) radios providing vehicle-to-vehicle communications. Further processing and fusion of the UGS, UGV, and MAV data was performed on this gateway HMMWV. The results were handed off to CERDEC-developed software, the C4ISR Information Management Service (CIMS), which routed the information to other vehicles over SRW and to the network operations center/tactical operations center via Warfighter Information Network-Tactical (WIN-T). Ultimately the information was displayed using a CERDEC-enhanced version of the Force XXI Battle Command, Brigade-and-Below (FBCB2) mapping system. Figure 1 provides a simplified, conceptual view of the communications links and deployment of various assets involved in the integration.

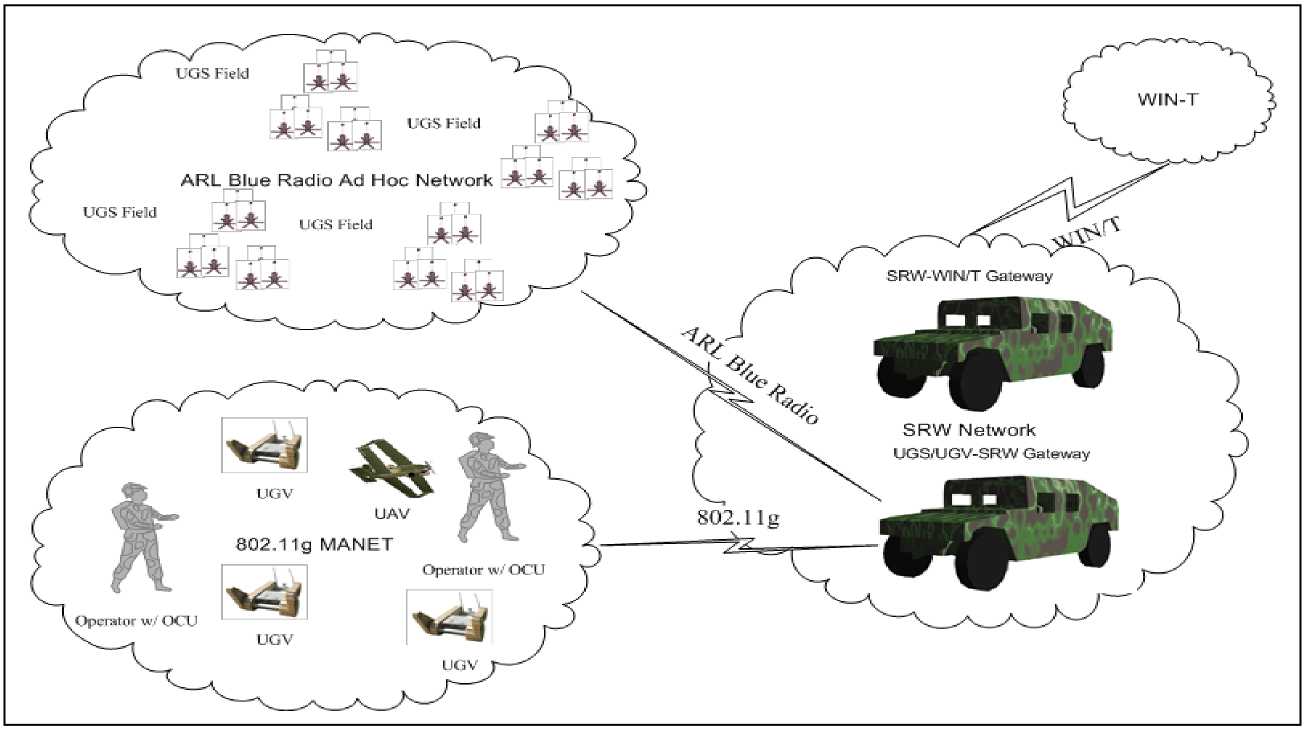

Figure 1. Simplified conceptual deployment of ARL assets in C4ISR OTM.

This report is organized as follows. First we describe the ARL software infrastructure and its integration into the SRW network and FBCB2. Next we describe the integration of the UGSs and associated software. The third section describes the UGVs and their integration and associated software. The fourth section describes the MAV integration. Instead of identifying future work in a separate section, each section contains its own future work sub-section.

2. Software Infrastructure

2.1 The Agile Computing Middleware

2.1.1 The Existing System

ARL began developing middleware during the mid-1980s to mediate between applications and heterogeneous communication services. While Internet Protocol (IP) had been adopted and standardized by that time, there were (and still are) a number of devices using a variety of other communication protocols. Many of these protocols are standards-based, but others remain proprietary. ARL adopted a middleware approach to isolating and protecting applications from changes in the underlying communications infrastructure. This middleware provided a layer of abstraction which allowed the applications to communicate seamlessly and transparently across a variety of devices, from experimental to operational, in-house and externally developed. With the award of the Advanced Decision Architectures Collaborative Technology Alliance in 2001,

ARL established a fruitful and ongoing collaboration with a group of researchers at the Institute for Human and Machine Cognition (IHMC) who shared a similar view of the benefits of middleware mediation. We began to explore the possibility of extending ARL's middleware to provide additional capabilities not readily available from the communications infrastructure. These additional capabilities focused on the opportunistic discovery and exploitation of available resources to improve capability, performance, efficiency, fault tolerance, and survivability. IHMC coined the term Agile Computing Middleware (ACM) (*2*) to emphasize the desire to both quickly react to changes in the environment and exploit transient resources which may only be available for brief periods. ARL and IHMC have since collaborated on the further development of the ACM and used it in the Horizontal Fusion Quantum Leap, Command and Control of Robotic Entities, and C4ISR OTM experiments and exercises. Some of the ACM capabilities utilized in these experiments and exercises include message-based communication flows along the orthogonal dimensions of reliability and sequencing[1], message tagging and replacement[2], a flexible peer to peer (P2P) dissemination and organization protocol, connection monitoring, and service discovery permitting the dynamic registration, deregistration and migration of arbitrarily complex services with arbitrarily complex signatures and parameters.

In addition, ACM, ARL, and IHMC developed a cross-layer network. The motivation behind the introduction of this new component arose as a result of the difficulties and vagaries encountered when introducing MANETs into various existing ARL systems. Generally, the introduction of MANETs has resulted in a rethinking of the sanctity of the OSI seven layer model[3]. While clearly a useful architectural abstraction for designing scalable solutions via clear separation of concerns, the dynamic properties of MANET environments[4] are causing researchers and developers to think about selectively exposing the layers to allow couplings to support timing guarantees, congestion control, quality of service (QoS) provisioning, and the like. In a wired environment, link bandwidth, error rates, and topology tend to be stable, allowing QoS to be determined upon the initial establishment of the connection with no need to modify path characteristics over the life of the connection. In a MANET environment, network characteristics can vary continuously depending on the degree of mobility of each of the constituent nodes. In addition to a dynamic topology, MANETs in tactical environments must contend with a multitude of noise sources and active interference, further increasing error rates

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[1] Flows can be selected from one of four possible combinations:

1) Reliable/sequenced messages are analogous to the delivery and sequencing guarantees provided by TCP.
2) Unreliable/unsequenced messages are analogous to UDP datagrams.
3) Reliable/unsequenced messages are provided for applications which want a delivery guarantee but don't care what order they arrive at the destination.
4) Unreliable/sequenced messages are provided for applications which don't care that all messages are delivered but do care that if they arrive, they arrive in the same order they were sent (such as some of forms of streaming video).

[2] To provide for replacement of one or more messages which have been queued but not yet transmitted and which have become obsolete because of newer information (such as current location or state).

[3] ISO/IEC 7498-1:1984, "Information Technology – Open Systems Interconnection – Basic Reference Model – The Basic Model".

[4] Mobility, energy concerns, spectrum/channel sharing, et al.

and decreasing bandwidth. If distributed systems in a MANET have access to lower-layer network information, they can be made more efficient and resilient by anticipating and adapting to changes in the network state[5]. Additionally, lower MANET layers which have access to application-level requirements and constraints can allocate resources more optimally. The cross-layer substrate provides a common interface, allowing applications to both query and inform lower layers in a consistent manner regardless of the types of devices, routing, or scheduling protocols in use on the network.

While applications which are individually aware of, and independently adapt to, changes in the network environment may result in more efficient usage of the available resources, they may also result in greater instability (e.g., as a result of competing requirements or greedy strategies). While nothing prevents applications from choosing their own adaptation strategy, group adaptation across an application's collective requirements is likely to yield better results. To that end, we are exploring using the ACM to provide collective QoS guarantees and dynamic adaptation across all of the applications within a distributed system in order to better[6] use the resources available at any given instant from a more global perspective.

Figure 2 illustrates the components and data flows within the middleware and cross-layer substrate. Mockets provides connection monitoring, message tagging and replacement, and (un)reliable/(un)sequenced communication flows. The Group Manager provides the flexible P2P dissemination and organization protocol, and AgServe provides for distributed, dynamic service (de)registration, discovery, and migration. FlexFeed provides intelligent distribution of content between nodes through the use of en-route message transformation and other techniques. The other components illustrated were not used within C4ISR OTM. More detail may be found in (*3 through 5*). Note that components within the ACM are designed to work with or without the cross-layer substrate. Similarly, applications can communicate directly with the cross-layer substrate, the ACM, or even the lower-level transport layer.

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[5] An immediate efficiency is to piggyback application data on top of any control traffic being generated by lower layers anyway for other purposes (e.g., the beacons and route maintenance messages associated with both proactive and reactive routing protocols).

[6] Decisions still have to primarily be made based solely on local decisions to minimize communications overhead introduced by the coordination itself. So the concept of a "globally optimal" solution is abandoned in favor of an adequate or sufficient assignment of resources.

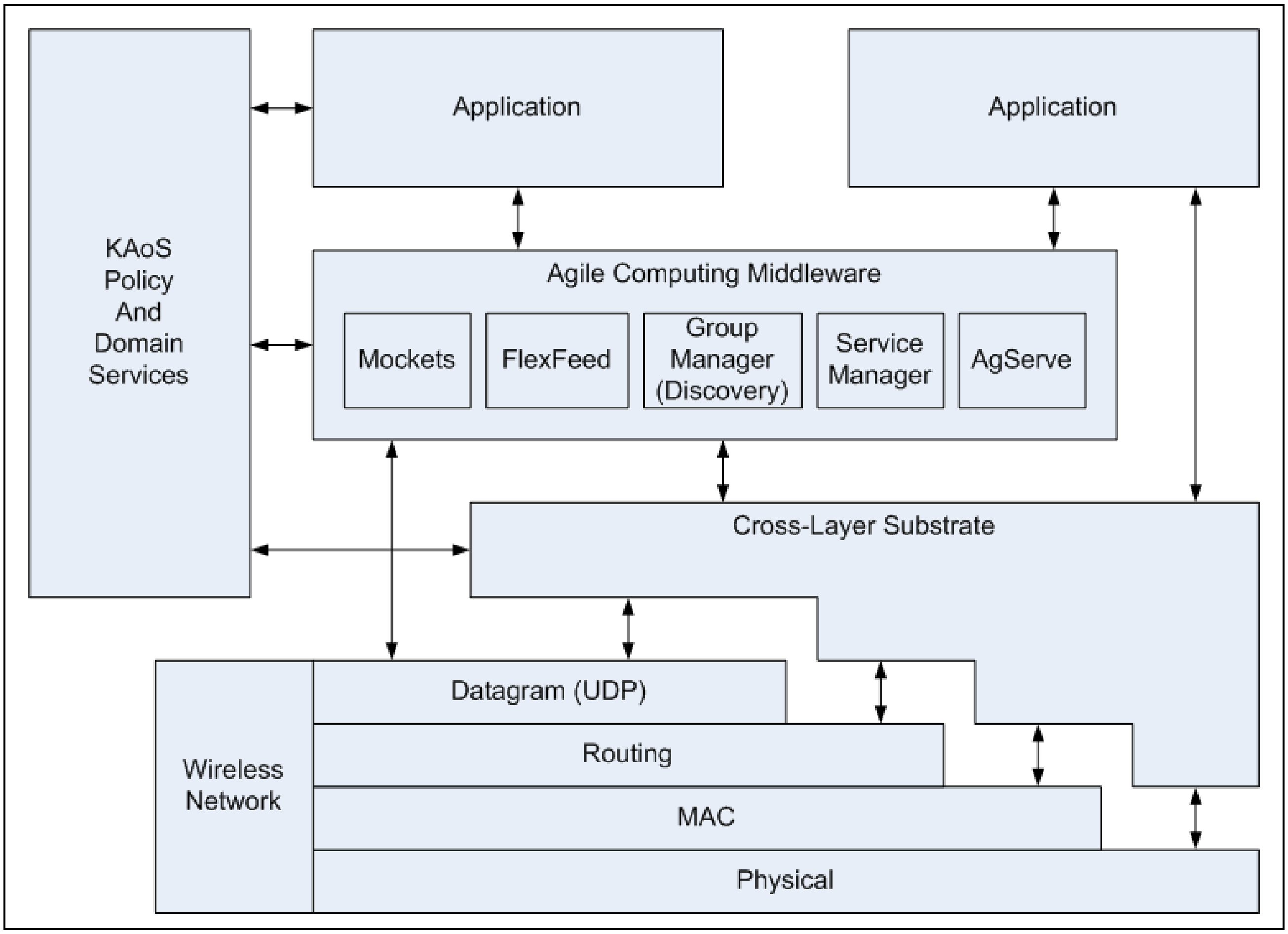


Figure 2. Agile computing middleware and cross-layer substrate.

2.1.2 Future Work, The ACM

Current efforts in this area include determining agility metrics to quantify the performance of the ACM, developing distributed collective coordination strategies, identifying topological and other communication characterizations which can support this distributed coordination, and integrating other communications devices within the cross-layer substrate (such as ARL's Blue Radio.)

2.2 The Servers

2.2.1 The Existing System

The current system is based around four centralized servers, each managing a different type of data. Producers generate data and route it to the appropriate server which then reflects the data to all interested consumers. The four servers are the TOS, the SOS, the Multimedia Server, and the Collaboration Server. This centralized approach to data storage and dissemination has proven to be inappropriate (if not infeasible) for a MANET environment and is used for historical reasons. Development of a distributed replacement for this architecture is underway.

Each server in the system advertises its service type, listen endpoint,[7] and protocol[8] via an ARL-developed surrogate for the AgServe middleware component called the AgentRegistry which internally uses the GroupManager for distributed dissemination. Clients query the AgentRegistry for the location of servers providing the services they require.[9] Clients initially connect to the server using the listen protocol specified in the server's service advertisement. Clients can negotiate a protocol change if the default listen protocol is not acceptable. Direct communications with the servers can be transported over transmission control protocol (TCP) or user datagram protocol (UDP) using standard sockets, or over (un)reliable/(un)sequenced Mockets message flows. Indirect communications via Web Services Definition Language web services are also supported via the introduction of specialized gateway clients created solely for this purpose.

The TOS processes MIL-STD-2525B-based extensible markup language (XML) messages. This server is used to disseminate position updates for every UGS, UGV, MAV, HMMWV, and other unit in the system. It is also used to disseminate operational and tactical graphics, enemy positions and activities, and any other information within the scope of MIL-STD-2525B. This information is ultimately visualized for the end user as symbols displayed on a mapping system.

The SOS collects and disseminates UGS detections and sensings. The server supports reporting of lines of bearing, proximal activity, electronic signatures and target locations. Messages to and from this server are formatted as XML conforming to an ARL-developed schema. This server's primary purpose is to provide a single collection point for data fusion applications. It is also used to support visualization of all sensor activity and state as an engineering or diagnostic aid.

The Multimedia Server stores and disseminates images, movies, audio reports, and other large binary objects. When multimedia data is collected by an UGS, an operator, or other process, the data and its associated metadata are pushed to the server which stores the data locally and reflects the metadata to notify other consumers of the existence of the new collect.

The Collaboration Server supports the tethering of map displays across users, the dissemination of attentional sketches and other graphical annotations, text chat, and file transfer. Users may collaborate using either a free-form or moderated protocol. In free-form groups users may join, leave, or create any session at any time; they may tether to/untether from, share sketches, send files, and chat with any other user in the session at any time. In a moderated session all of these activities must be approved (at least initially) by the moderator. By default, the moderator is the user who created the session, but any user who later joins can become the moderator with the

[7] IP address and port number.

[8] TCP, UDP, or Mockets.

[9] This query is typically persistent allowing clients to request a server which is not yet available, continue to do other processing, and then connect to the server asynchronously later when its existence is pushed to them. Via the connection monitoring capabilities of the middleware, it also allows for servers to disappear and reappear (for whatever reasons) with minimal impact on the clients.

current moderator’s approval. Moderators can also force other users to tether their map to another user (or nobody), and to share their sketches or not.

None of these servers have inherent support for persistence. Persistence is provided via special consumers which attach to the servers and store the reflected reports in a database or other file.

Figure 3 shows the deployment of these servers and supporting software within the C4ISR OTM experiment. The servers were intentionally deployed on a vehicle other than the UGS-UGV/SRW Gateway HMMWV to demonstrate that the ACM, cross-layer, and distributed discovery components would interoperate seamlessly across different networks.

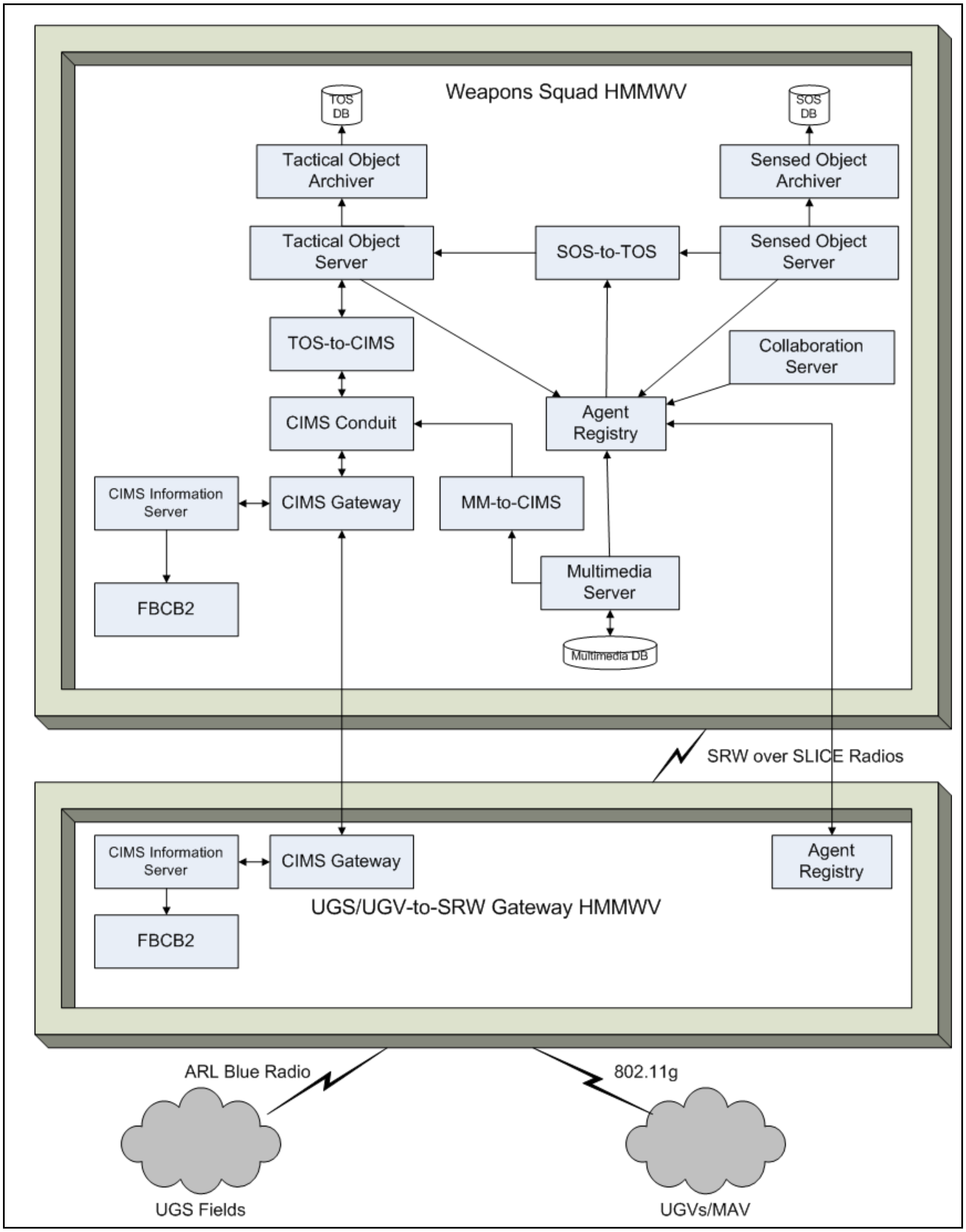


Figure 3. ARL server deployment and integration w CIMS and FBCB2.

In addition to the ARL servers and archiving clients described above, a set of fusion process collectively known as Sensed Object Server (SOS)-to-Tactical Object Server (TOS) receives raw detections from the SOS and sends MIL-STD 2525B unidentified, unaffiliated ground track symbols to the TOS for dissemination. Unknown ground track symbols are created where acoustic bearings within a temporal window intersect and at the location of a tripwire or

proximity sensor detecting activity. Since there was no facility within FBCB2 for displaying raw sensor activity, these unidentified moving object symbols cued the FBCB2 operators where activity was occurring and which camera captures should be examined. To minimize the amount of clutter on ARL's map display, SOS-to-TOS deletes the detection symbols from the TOS after 10 seconds. FBCB2 has its own decay mechanism that ages symbols based on time of last report. SOS-to-TOS also sends sensor status reports to TOS every 5 minutes to inform the operators of UGS state and to prevent FBCB2 from aging the UGS symbols away.

TOS-to-CIMS and MM-to-CIMS attach, respectively, to the TOS and Multimedia Server as clients. They expose a listen socket on a predefined port that the CIMS conduit attaches to. Received data is passed to the CIMS conduit via the socket. For tactical symbols, this communication is bidirectional. The CIMS Conduit uses the CIMS Gateway to provide reliable communications over the SRW SLICE network and wraps additional user interface (UI) elements around FBCB2 to provide network status, chat, and imagery capabilities via the CIMS Information Server. Figures 4 and 5 show examples of the CIMS-enhanced FBCB2 display that was presented to the operators.

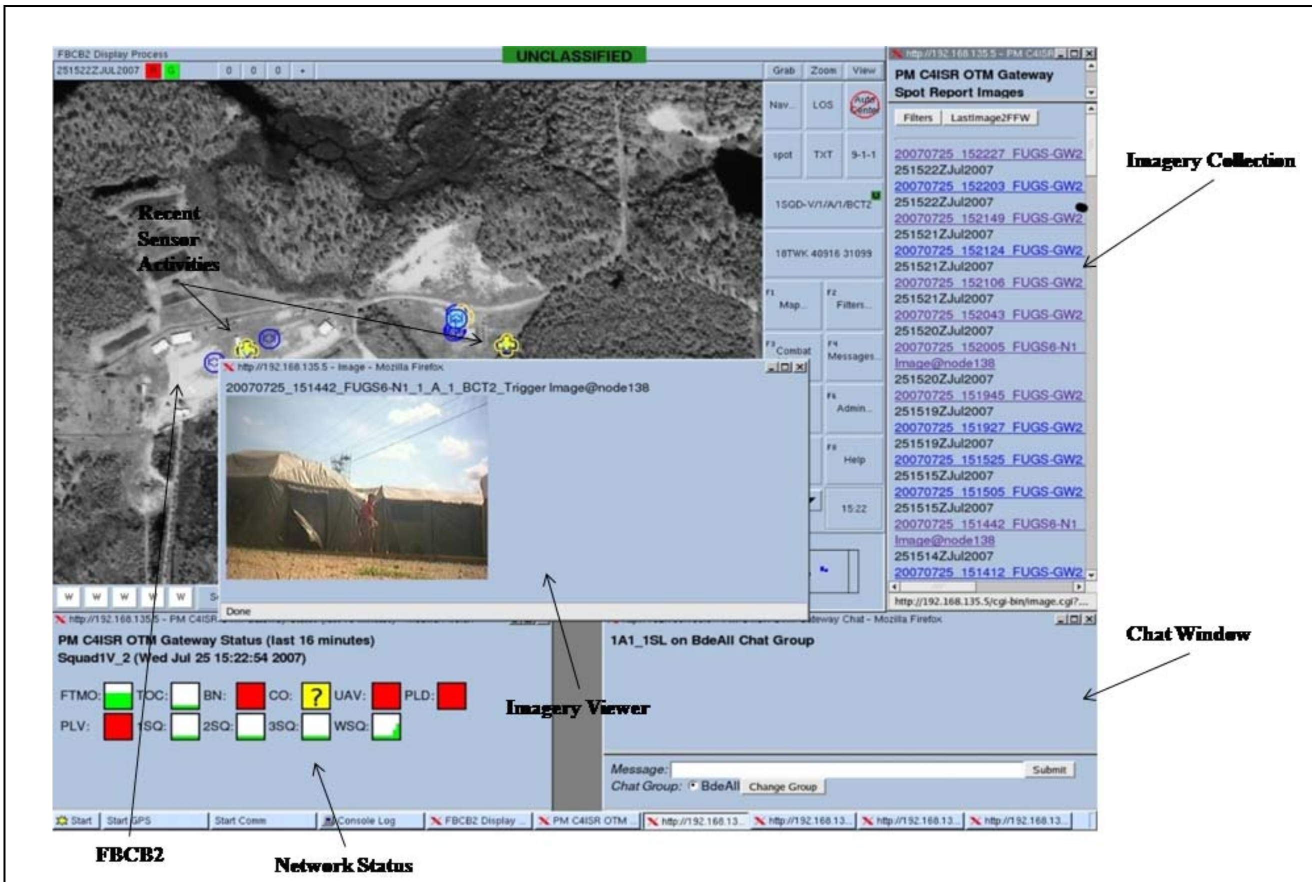


Figure 4. CIMS enhanced FBCB2 showing sensor imagery.

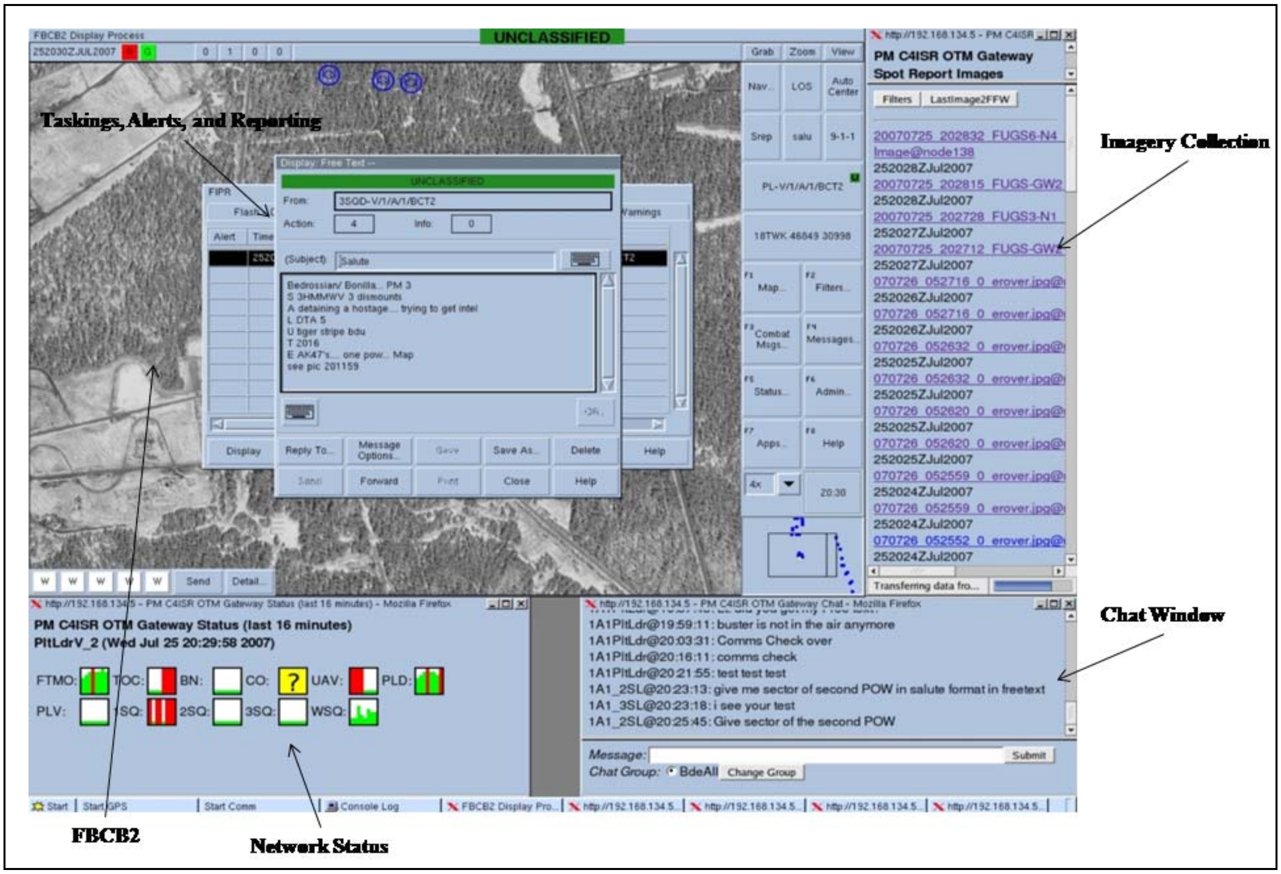


Figure 5. CIMS enhanced FBCB2 showing text information.

2.2.2 Future Work, The Servers

The major problem with the current architecture is the reliance on communication with a centralized server. Such communication cannot be guaranteed in the highly mobile, intermittently connected network environment typical of MANETs. However, there are advantages to this centralized approach in more robust environments like those provided by WIN-T and the global information grid. Our current development efforts focus on removing the dependencies on these servers by relocating them from the core to the periphery of the system, where they will continue to serve as gateways to other systems. To accomplish this, we plan to create specialized P2P groups using the Group Manager component in the ACM. The data reflection function currently performed by the servers will be replaced by dissemination through these P2P groups. External systems can continue to interface with the ARL system by sending and receiving information using the current server interfaces, but the gateway servers will simply function as peers within the P2P group and will no longer maintain the single, authoritative data repository.

A more subtle problem with the current architecture is that the servers typically maintain a thread for each connected consumer and unicast all reflected data to them. This is clearly inefficient when most or all of the clients have the same data requirements. Moving to the distributed P2P

approach will allow us to gain some efficiencies from the multicast strategy used by the Group Manager. In situations where clients have differing data requirements, an intelligent approach like that provided by FlexFeed within the ACM is more appropriate.

Different types of servers will warrant different P2P strategies and structures. For supporting and maintaining situational awareness by periodically distributing position data to all nodes as efficiently as possible, simple epidemic and broadcast protocols may suffice. For sensor and data fusion, the data may be useless if it isn't delivered to fusion centers quickly and efficiently. In this case, the fusion centers (and the communication routes to them) become differentiated from their peers by virtue of their importance. For human collaboration, the peers and groups emerge dynamically as a result of user-to-user interactions[10] and may bear little resemblance to the underlying network topology. In these situations it is advantageous to dynamically adapt the dissemination protocol and associated distributed data structures to better match the higher level network environment.

2.3 The Map Display

2.3.1 The Existing System

The mapping system ARL used for this effort was developed beginning in 2002 as a project for the Intelligence and Security Command (INSCOM). The fundamental ideas were that 1) map displays can be tethered to ensure that collaborators are "on the same page", 2) sketches and other annotations drawn on the map can be shared to enhance collaboration, and 3) laydown of control measures and other tactical graphics specified in MIL-STD-2525B can be facilitated by allowing users to draw them free-hand with a touch screen, stylus, or mouse. Because of its focus on the use of free-hand drawings to support collaboration and intelligence preparation of the battlefield, this application, coupled with the Collaboration Server and supporting infrastructure, became known as Digital Ink.

Digital Ink is implemented as an extension into ESRI's ArcMap application. It consists of 3 main components: symbology, collaboration, and sensor coverage display. The symbology component supports the free-hand lay-down and real-time display of MIL-STD-2525B symbology. MIL-STD-2525B specifies graphical templates for each of the symbols. The standard provides a different template for each symbol. We classify each template into one of ten categories (detailed in the appendix.)

While many systems use the individual symbol templates explicitly for both symbol creation and manipulation, there may be efficiency gains if these template categories are superimposed on appropriately attributed[11] free-hand drawings and the defining points are extracted algorithmically. In this system, users select the type of symbol they want to create from a

[10] Who wants to (or should) tether to whom, who wants to (or should) share sketches or other attentional ink or graphical annotation with whom.

[11] Namely with the MIL-STD-2525B symbol identification code.

graphical palette of recently or frequently used symbols.[12] They are then prompted to draw the appropriate category (draw a U for a U-shaped template category, draw a J for a J-shaped category, etc.). Once this has been done, they draw the location and basic shape for the category. The defining points for the template category are then extracted, and a new symbol is added to the user's map and sent to the TOS for dissemination to others. The real-time rendering of symbology is implemented by double-buffering the map display generated by ArcMap and sending the bitmap and associated geographic coordinates to TRW's Graphical Symbology Display library to render the symbols.

The collaboration component supports user-to-user collaboration through the Collaboration Server. Users can share sketches and other graphical annotations, tether map displays, chat and send files via this interface. When sharing sketches, the client-side application renders each line segment as it is received instead of waiting until the entire sketch has arrived. This effectively captures the temporal aspect associated with the creation of the sketch allowing users to convey a sense of urgency to their annotations. Figure 6 shows an example of the tethering and sketch sharing UI with some explanatory notations. Figure 7 shows an example of the chat and file sharing UI.

[12] Or using a dictionary indexed along a variety of dimensions including lexically and hierarchically.

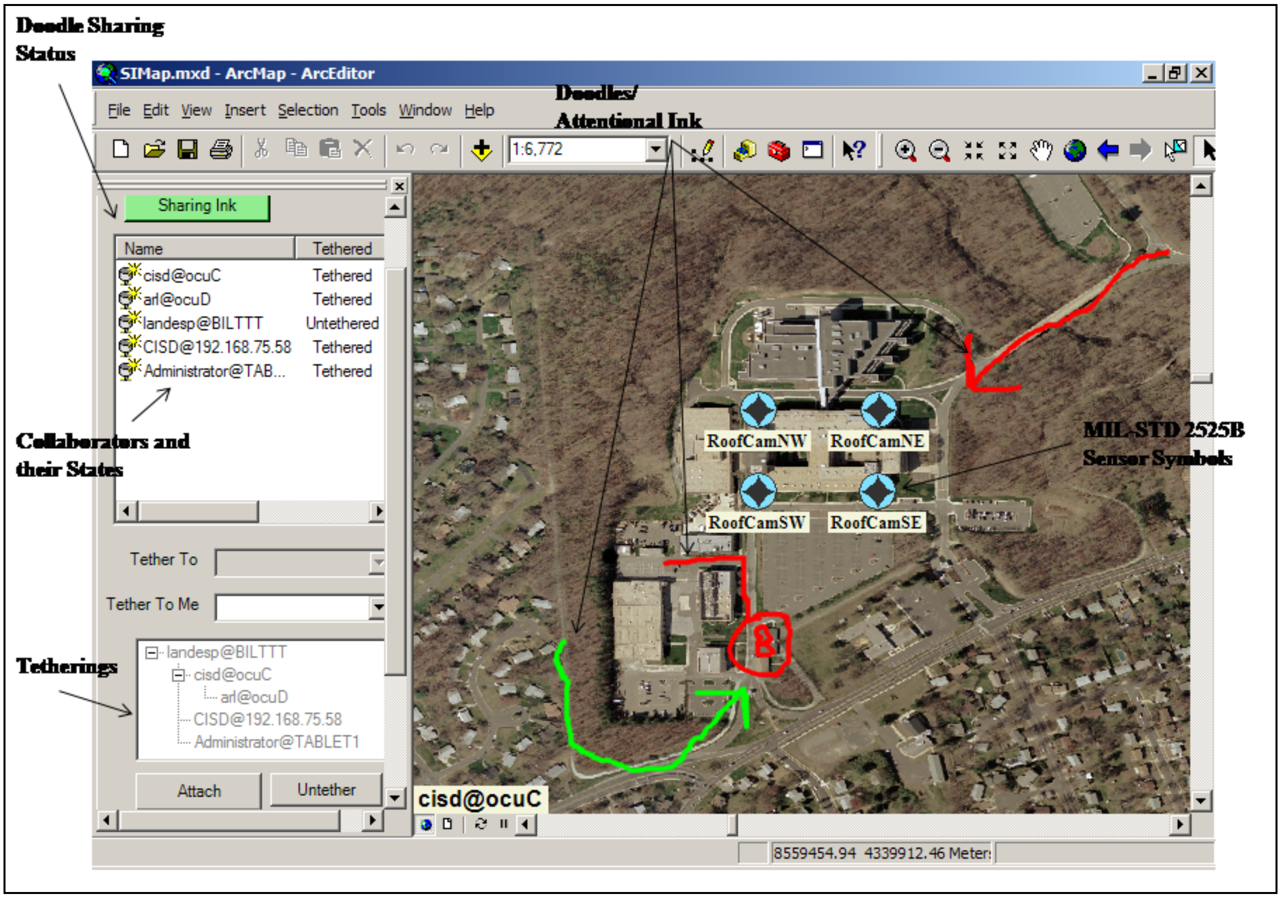


Figure 6. Collaborative map tethering and doodling – Sketch Sharing.

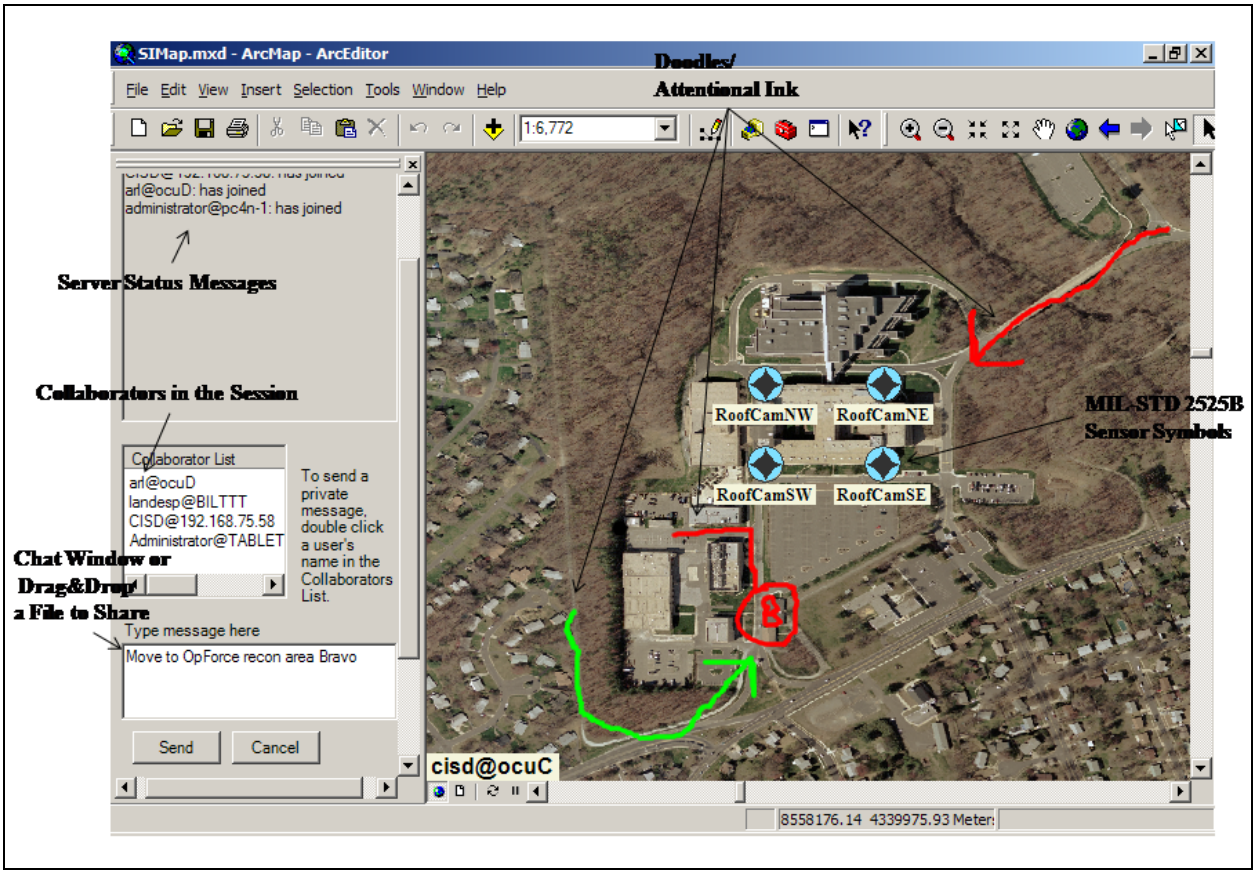


Figure 7. Collaborative map tethering and doodling – File/Chat Sharing.

The sensor coverage component is used to display range fans, lines of bearing, directional arrows, and other detection indicators to illustrate sensor coverage and activity. Examples of these capabilities are shown in figure 8.

In the upper center portion of this the range fans of two cameras mounted on a building roof are displayed. The coverage than can be achieved by these cameras is reported by the camera rather than being "made up" by the display program. As a consequence, the map display has the ability to display "true" information which may be used by the operator for planning purposes. Note from the figure that the upper two cameras (looking Northward) have overlapping fields of view. In situations such as this, it is possible to transfer use of one camera to another as an object of interest moves from the view of one camera to the view of both cameras to the view of the other camera.

Also shown in figure 8 is an infrared tripwire sensor. This sensor is the yellow symbol just to the right and below the center of the figure. The field of view of this sensor is shown in a manner that is identical to the field of view display for the camera. That is, the field of view is reported by the sensor it self. This particular tripwire sensor also reports the line of bearing of objects that cause it to trip. The red line that runs up center of the field of view of the tripwire sensor is such a report.

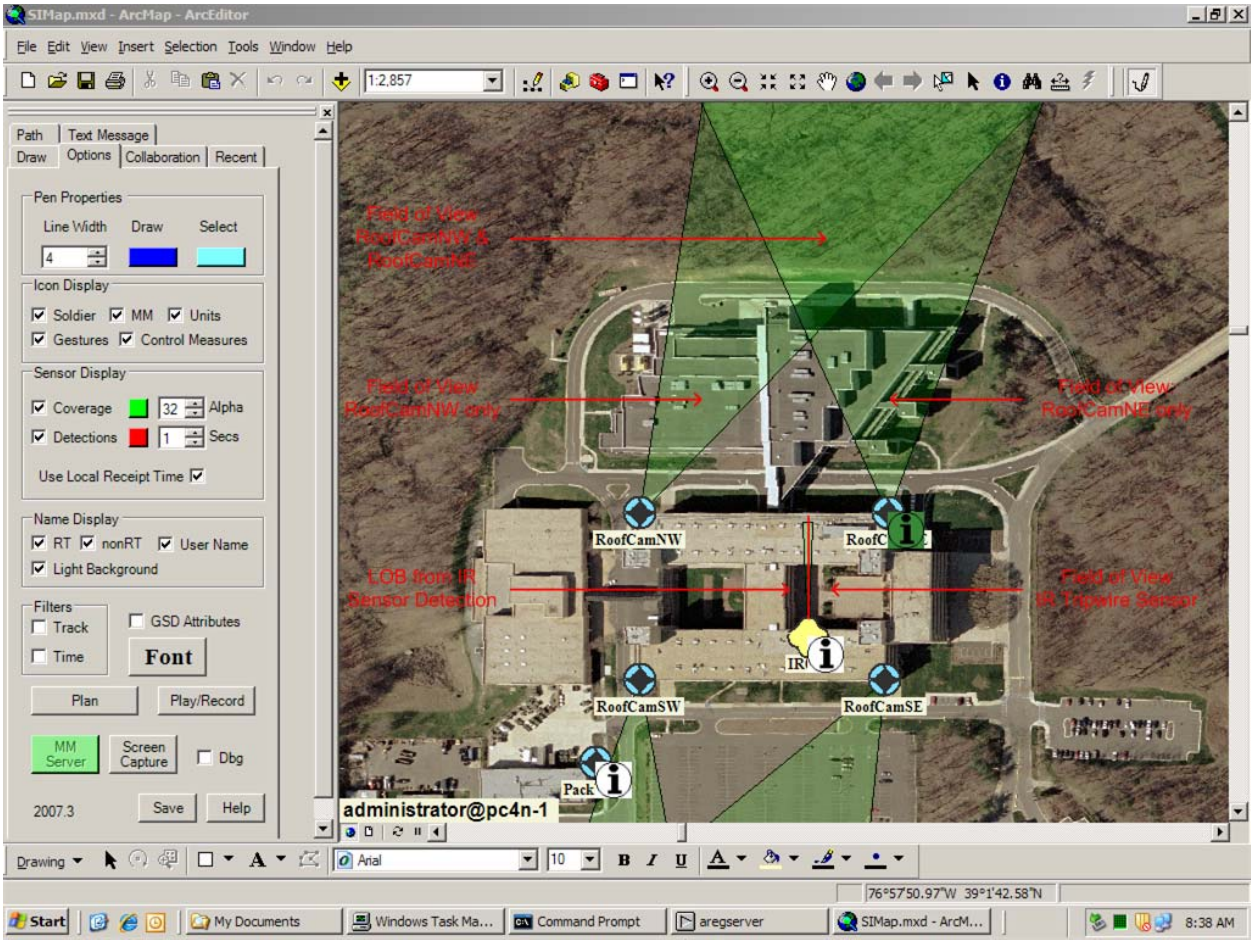


Figure 8. Sensor coverage and detection.

As the sensors themselves are actually reporting their characteristics, the map display can be a very useful tool in planning the location of sensors and a very useful tool for analyzing targets as they move through fields of sensors. It is also true that since the sensors report their own characteristics, there is a potential to automate much of the processing that might be done by a human using the map display as an analysis tool.

2.4 Future Work, The Map Display

Digital Ink is currently integrated with ESRI's ArcMap application as an ArcMap extension. We decided to plug into ArcMap instead of using ESRI's ArcEngine as a library underneath an ARL application because INSCOM Intelligence Analysts were already familiar and comfortable with ArcMap. With the award of the Commercial Joint Mapping Toolkit (C/JMTK) contract, a DoD-wide license has been created for the development of C2 systems. The ArcEngine and associated developer kit are included in the license agreement, but the ArcMap Desktop application is not. Our current efforts include re-implementing Digital Ink as a standalone application using ArcEngine. Additionally, TRW's Graphical Symbology Display is no longer supported, so we

are replacing the rendering of symbology with ESRI's Military Overlay Editor, which is part of the C/JMTK.

3. UGS Integration

3.1 The UGS

ARL integrated four operational and two experimental UGS systems into the C4ISR OTM experiment. Three of the operational systems were developed for the Army and one was developed for the United States Marine Corps (USMC). The Army UGS included one OmniSense system provided by McQ Inc., one Scorpion system provided by Northrop Grumman, and one Silent Watch system provided by Harris. The USMC UGS consisted of one Tactical Remote Sensor System (TRSS). All four sensor systems contained at least one imager. To minimize power consumption, the imagers and associated processors typically remain in a low power state until cued by activity sensors. The activity sensors on all four operational systems are capable of detecting both vehicles and personnel in the vicinity. The OmniSense system employed in the experiment consisted of visible and thermal imagers cued by seismic, acoustic, and passive infrared (PIR) activity sensors. The Scorpion system contained both visible and thermal imagers cued by magnetic and seismic activity sensors. The Silent Watch system contained a low light visible imager and an thermal imager cued by seismic and PIR activity sensors. The TRSS contained visible and thermal imagers cued by activity sensors which can be configured to use acoustic, seismic, or PIR transducers.

ARL also integrated two internally developed experimental sensor systems: a MMS system and a Tripwire Camera (TWC). The MMS is a very low-cost non-imaging system consisting of a number of single-package seismic, acoustic, and PIR transducers. Depending on the desired or observed specificity and sensitivity during operations, the MMS can be configured to generate activity reports only when certain combinations of the three sensors are activated. The MMS does not provide localization and only reports that activity is occurring in its proximity. One MMS sensor suite, consisting of six sensors and a gateway node, was employed during the experiment. The TWC consists of an off-the-shelf low-cost daytime color imager commonly used in cell phones cued by a PIR motion detector. The camera remains idle until the PIR detector activates it in response to motion in its field of view. After image capture, the image and direction of motion are packaged into a sensor report for delivery back to the UGS/UGV-SRW gateway HMMWV. Two TWCs were employed during the experiment.

3.2 The UGS Communications

While each UGS comes with its own communications system, ARL is promoting the idea of common communications protocols and devices as part of its Family of UGS concept. As ARL has not yet identified a suitable standard protocol and the developers of three of the four

operational systems already had some experience with McQ Inc.'s Common Data Interchange Format (CDIF), for the sake of expedience CDIF was chosen as the common communications protocol for this experiment. ARL's Blue Radio was used as the common communications device. The Blue Radio provides secure long range data communications in the tactical ultra high frequency (UHF) frequency band. Battery life is maximized by intelligently managing the transmitter and receiver power of the radio. Multiple radios will discover each other and form an ad hoc network amongst themselves. Although direct communications between any two radios is possible, in practice one or more radios is configured to be a gateway or sink which every other radio will establish a route to.

For C4ISR OTM, a Blue Radio was mounted in the UGS/UGV-SRW gateway HMMWV and configured as the only gateway in the Blue Radio network. Since OmniSense already used the CDIF protocol, the only change required to integrate it into the experiment was to replace its communications device with the Blue Radio. For the Scorpion and Silent Watch sensors, a separate laptop computer was used to bridge between them and the Blue Radio network. Since these systems already used serial radios for their native communications, the original radio was simply removed and replaced by the laptop/Blue Radio equipment. The radio plugged into a second serial port on the laptop. Additionally, Scorpion and Silent Watch used the laptop to translate from their native protocol into CDIF just prior to transmission over the Blue Radio. There was insufficient time to translate the TRSS native protocol into CDIF; the Blue Radio was already integrated with its imager's processor. As a result, no laptop was necessary, but special TRSS message handlers had to be installed on the UGS/UGV-SRW gateway HMMWV. The TWC and MMS were designed to use the Blue Radio natively so no laptop or other communications bridge was necessary. However, there was insufficient time to develop the software to translate their native protocols into CDIF so special handlers were installed on the gateway similar to the TRSS. Figure 9 shows the deployment of relevant components used during the experiment from the perspective of the UGS.

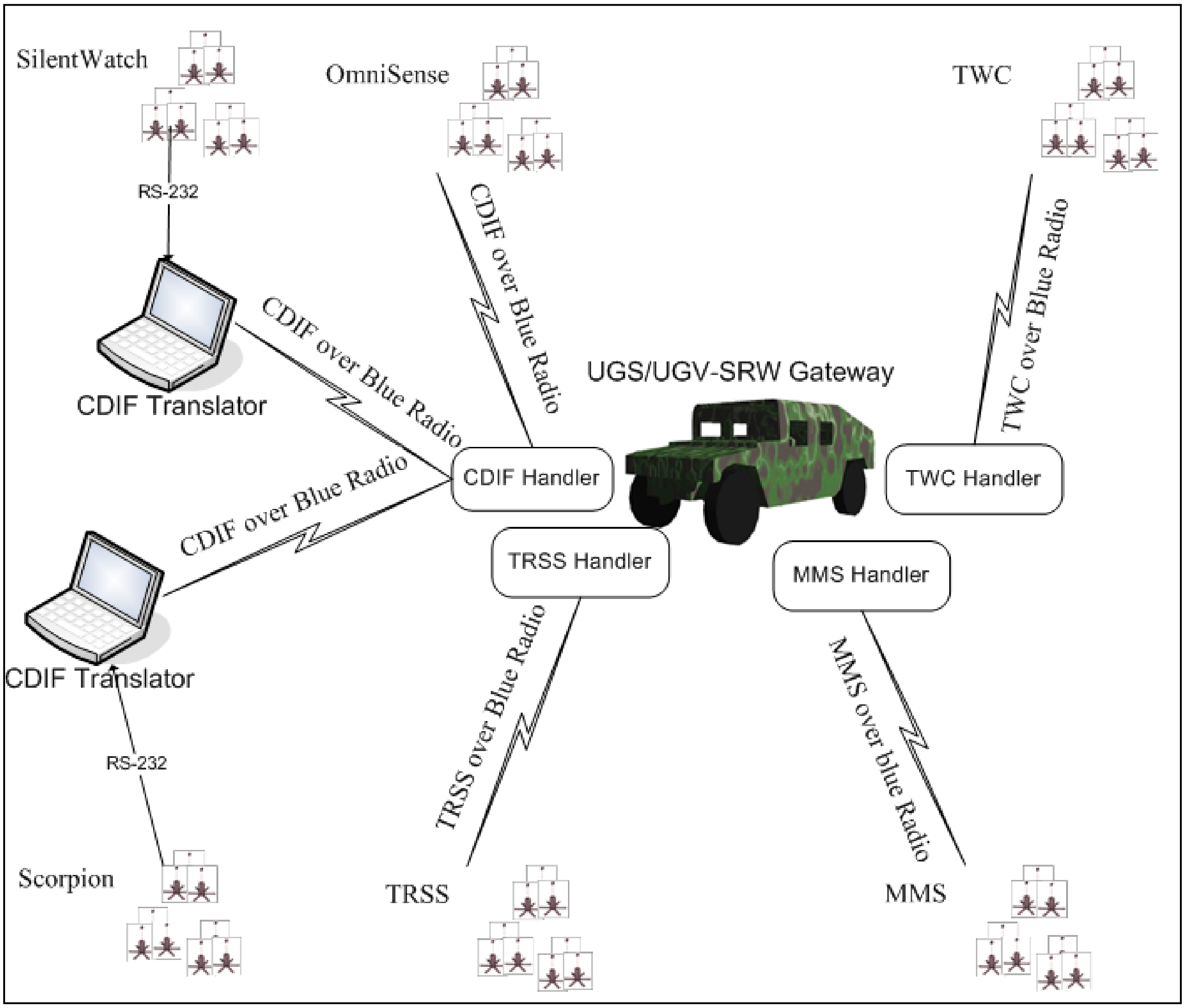


Figure 9. UGS integration architecture.

4. Unmanned Vehicles

4.1 Unmanned Ground Vehicles

ARL integrated three iRobot PackBot Explorers into the experiment. The PackBots were equipped with a communications payload developed by ARL and IHMC. This payload consisted of a Linksys 802.11g wireless router running OpenWRT Whiterussian custom firmware and an open source Optimized Link State Routing (OLSR) routing daemon. In addition to the custom payloads, ARL developed its own OCU software. This software was installed on ruggedized Itronix Duo-Touch Windows XP Tablet PCs that had been modified to use Army standard BB-2590 compatible batteries. Communications were provided by the same type of Linksys router used on the PackBot communications payload. The OCU was equipped with dual CH Products industrial joysticks mounted on a frame bolted to the tablet PC. Three OCUs were used during the experiment. Figure 10 shows the OCU hardware. The Linksys router is mounted underneath the tablet.

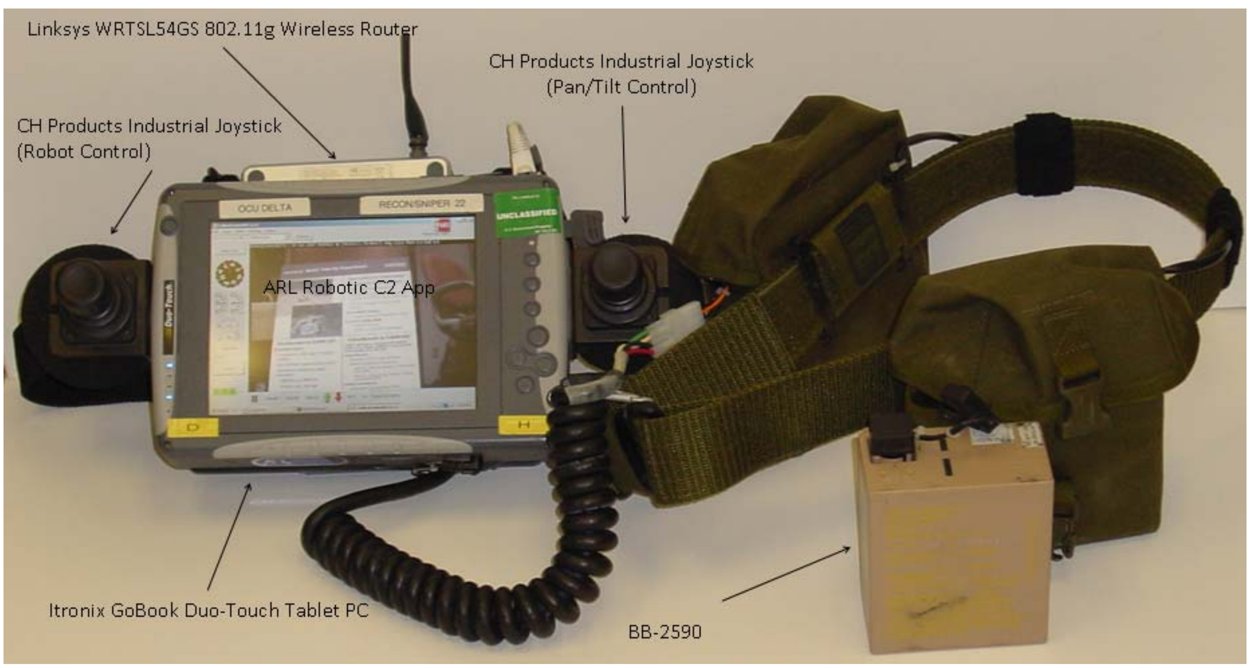


Figure 10. ARL OCU hardware.

A communications payload similar to that on the PackBot was mounted on the UGS/UGV-SRW gateway HMMWV. UGV and OCU data were routed to the TOS for dissemination to other OCUs (for SA), to higher echelons via WIN-T, and to other local HMMWVs via SRW. The

software components and data flow for these activities is described in more detail in a later section. Figure 11 shows the asset deployment and communications links from the UGV perspective.

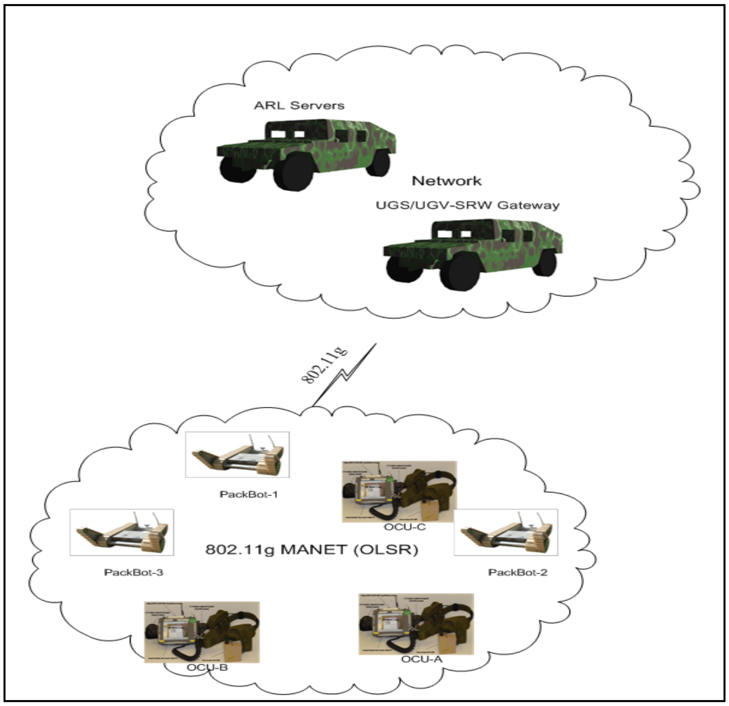


Figure 11. UGV integration (communications).

In addition to the new payload, ARL installed video, control, telemetry, and middleware software on the main PackBot processor. ARL's control and telemetry software uses the iRobot Aware 1.2 Robot Intelligence Software to control the PackBot and acquire positional and other telemetry data. The video software replaces the iRobot video server and supports sending either MPEG-4 or Motion JPEG video streams to an arbitrary number of clients at user-selectable frame rates, resolutions, and compression levels. The control software supports both low-level (e.g., move forward at 1 m/s) and mission-level (e.g., navigate to these waypoints) commands. Both the video and control software advertise their services through the distributed discovery mechanisms provided by the ACM.

The OCU software consisted of the Digital Ink map display described earlier which provided SA for the PackBots' positions and all other global positioning system (GPS)-equipped assets in the experiment combined with a C2 application which allowed the operators to control and monitor any of the robotic assets. Operators have the ability to capture and annotate individual images from any of the video feeds and submit them to higher echelons. Any OCU can be used to control any robotic asset. Operator contention is handled by locking out other operators once an OCU has control. The current availability status of the robot is indicated on the display. A commandeer capability exists allowing an operator to override this lockout in an emergency or

exceptional situation. The OCU software uses the distributed discovery services provided by the ACM to discover the available robotic assets. Figure 12 shows an image of the OCU control software.

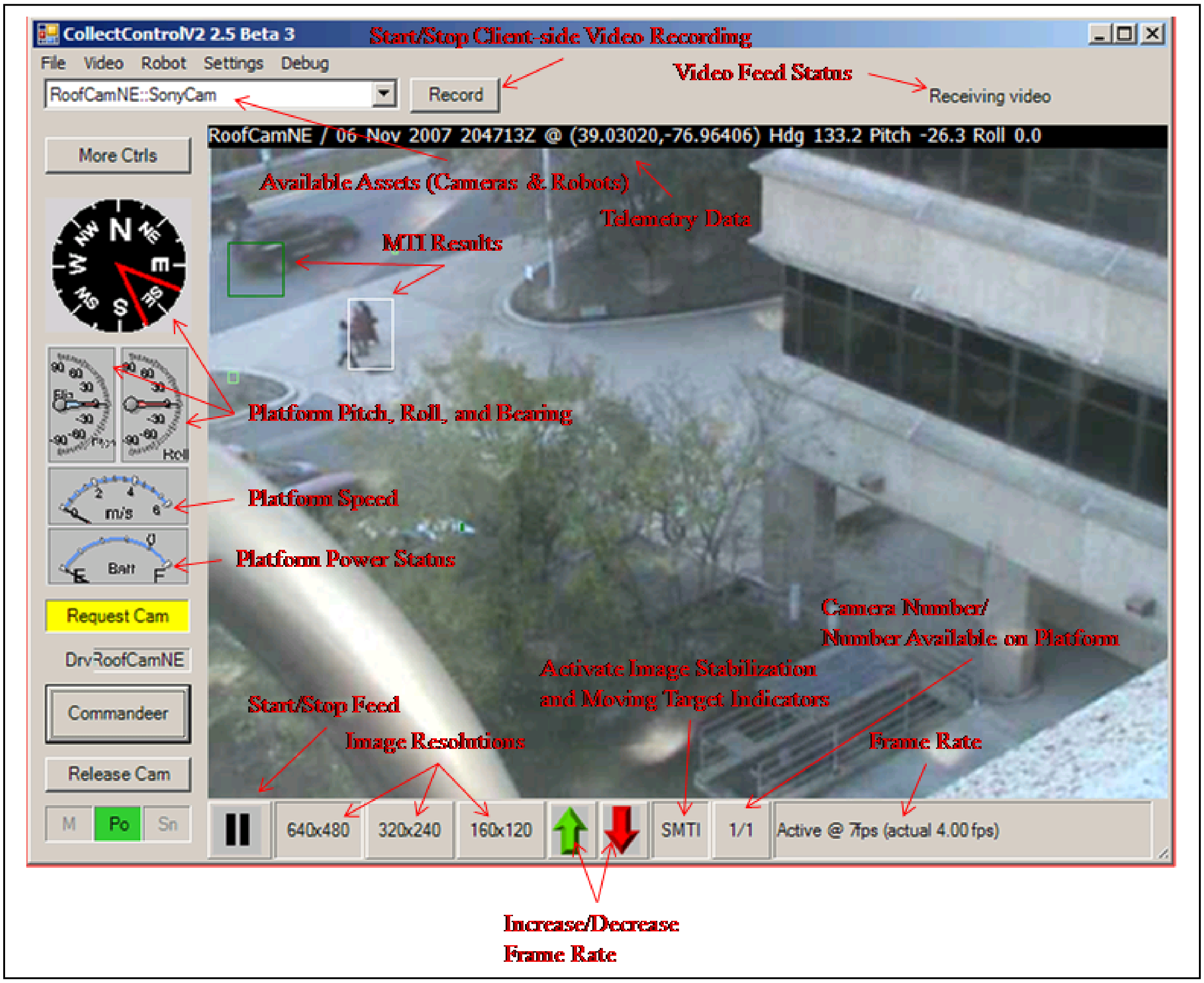


Figure 12. ARL UGV OCU C2 application.

4.2 Micro Air Vehicles

ARL partially integrated the Nighthawk MAV developed by Applied Research Associates into the C4ISR OTM experiment. The Nighthawk is a man-portable, hand-launched unmanned air vehicle capable of autonomous flight using an integrated GPS and autopilot. The vehicle is equipped with multiple video cameras. The Nighthawk system is comprised of the MAV itself, a laptop-based control station, and a remote video receiver. The control station uses the FalconView mapping system for MAV tasking and SA.

ARL injected the MAV telemetry data into C4ISR OTM by connecting a gateway laptop to a serial port on the control station laptop that was configured to stream NMEA 0183-like telemetry data. This data was sent to the TOS for further dissemination. The remote video terminal received wide-band NTSC analog video over a 2.4GHz link. The NTSC-Out port of the remote video receiver was connected to a USB frame grabber on the gateway laptop and exposed the video feed to remote systems in the same manner as that described for the UGVs. Figure 13 shows the deployment of relevant components used during the experiment from the perspective of the MAV integration.

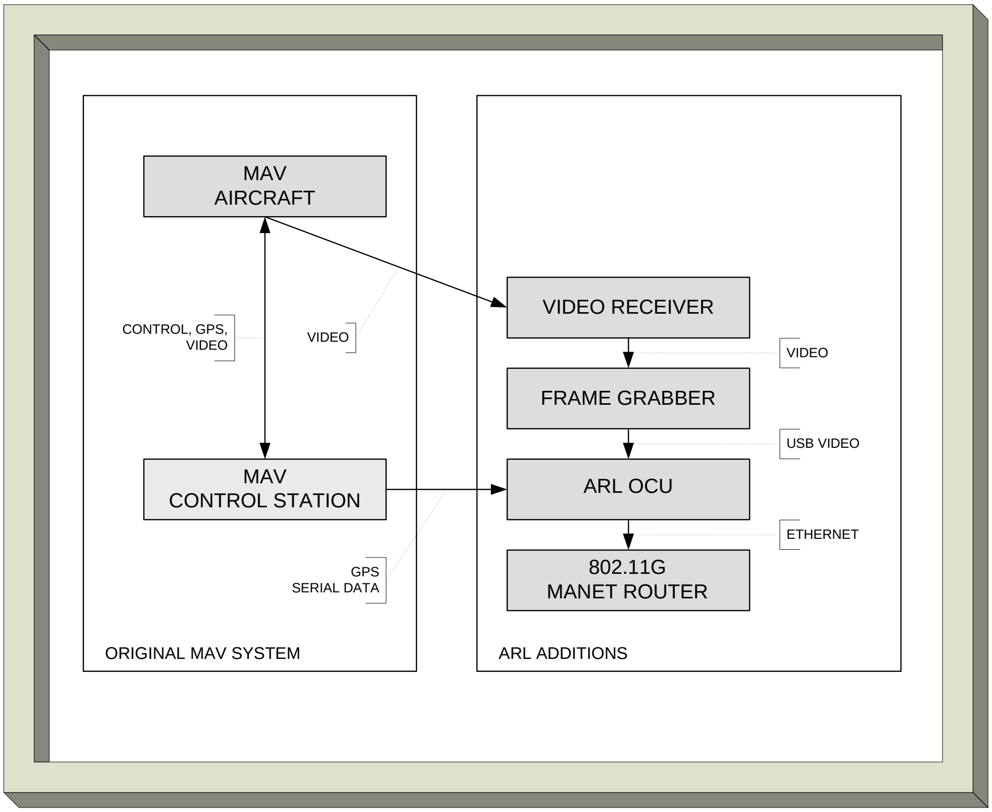


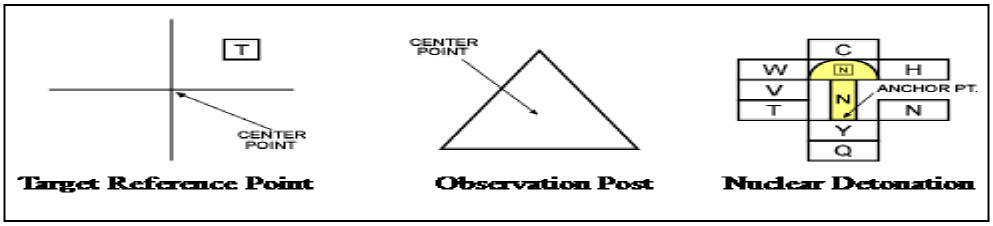
Figure 13. MAV integration architecture.

4.3 Future Work

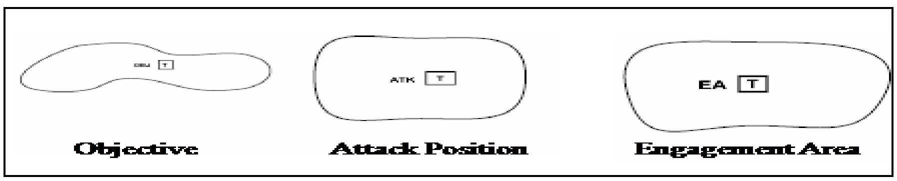
As part of the Family of UGS concept, ARL is investigating the use of cross-asset tipping and cueing between UGS, UGVs, and MAVs. For example, an UGS field may exhibit enough interesting activity to warrant further investigation. This further investigation could be carried out autonomously by UGVs or MAVs if the assets could be automatically tasked. Initially, we plan to generate waypoints and missions based on UGS and UGV reports and task the Nighthawk MAV using STANAG 4586 messages sent to a socket-based server running on the Nighthawk control station.

Appendix: MIL-STD-2525B Symbol Classification

1) Point templates have a single anchor point,

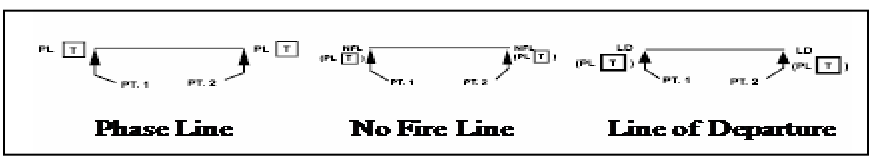


2) Area templates use all of the input points,

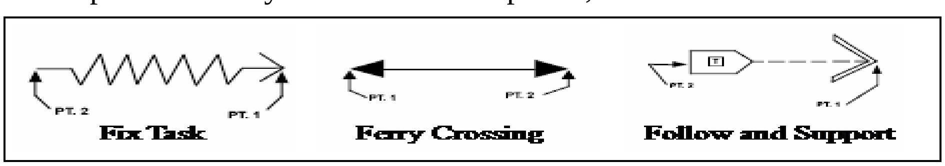


3) Line templates

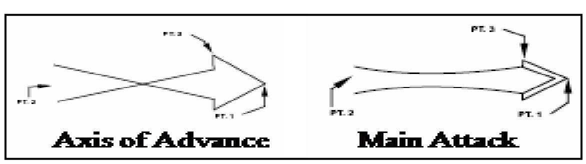
a. Unsampled line templates use all of the input points with the start and end points designated as anchor points,



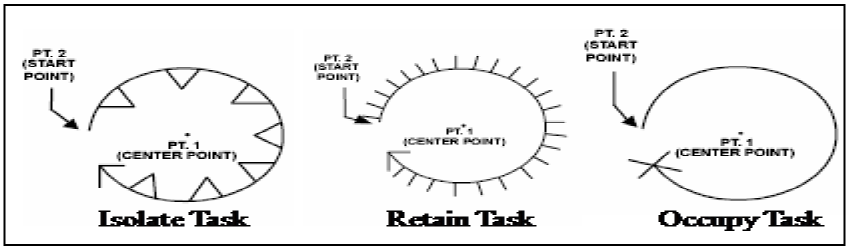
b. 2-point line templates use only the start and end points,



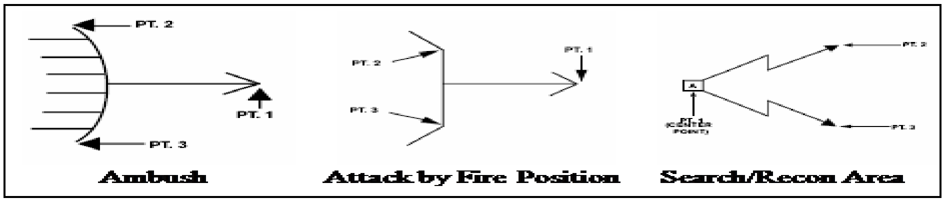
4) Arrow templates use the start point, the tip of the arrow head, and the location of one of the arrow head end points as anchor points,



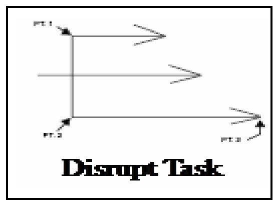
5) Circle templates use the start point and the center point as anchor points,



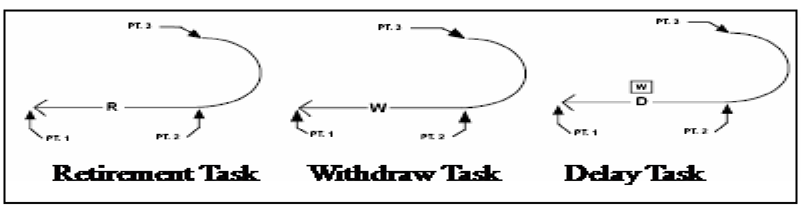
6) V-shaped templates use the base point of the V and the 2 top end points as anchor points,



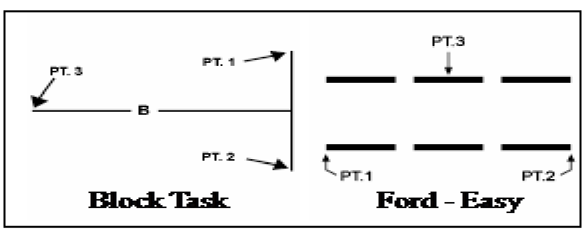
7) L-shaped templates use the start point, bend point, and end point as anchor points,



8) J-shaped templates use the start point, bend start point, and end point as anchor points,

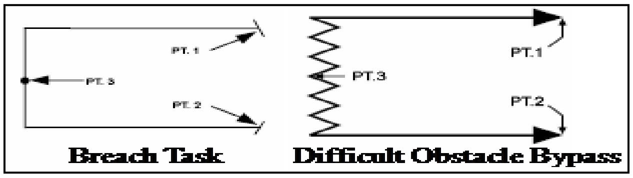


9) T-shaped templates use the two top end points and base point as anchor points,

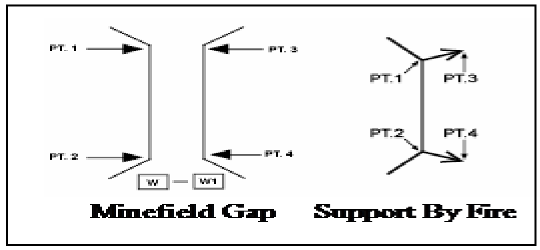


10) U-shaped templates

a. 3-point U-shaped templates use the two top end points and the mid-point of the base as anchor points,



b. 4-point U-shaped templates use the two top end points and two base points as anchor points,



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Acronyms

ACM	Agile Computing Middleware
ARL	Army Research Laboratory
C/JMTK	Commercial Joint Mapping Toolkit
C2	Command and Control
C4ISR OTM	Command, Control, Computers, Communications, Intelligence, Surveillance, and Reconnaissance On-the-Move
CDIF	Common Data Interchange Format
CERDEC	Army Communications, Electronics Research, Development, and Engineering Center
CIMS	C4ISR Information Management Service
DoD	Department of Defense
FBCB2	Force XXI Battle Command, Brigade-and-Below
FCS	Army Future Combat Systems
GPS	Global Positioning System
HMMWV	High Mobility Multipurpose Wheeled Vehicle
IHMC	Institute for Human and Machine Cognition
INSCOM	Army Intelligence and Security Command
IP	Internet Protocol
MANET	Mobile Ad-Hoc Network
MAV	Micro Air Vehicle
MIL-STD-2525B	Department of Defense Common Warfighting Symbology Standard
MMS	Multi Modal Sensor
OCU	Operator Control Unit
OLSR	Optimized Link State Routing
OSI	Open Systems Interconnection

P2P	Peer to Peer
PIR	Passive Infrared
QoS	Quality of Service
SA	Situational Awareness
SLICE	Soldier-Level Integrated Communications Environment
SOS	Sensed Object Server
SRW	Soldier Radio Waveform
TCP	Transmission Control Protocol
TOS	Tactical Object Server
TRSS	Tactical Remote Sensor System
TWC	Tripwire Camera
UDP	User Datagram Protocol
UGS	Unattended Ground Sensor
UGV	Unmanned Ground Vehicle
UHF	Ultra High Frequency
UI	User Interface
USMC	United States Marine Corps
WIN-T	Warfighter Information Network-Tactical
XML	Extensible Markup Language

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